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TECHNOCONCEPTS INC.

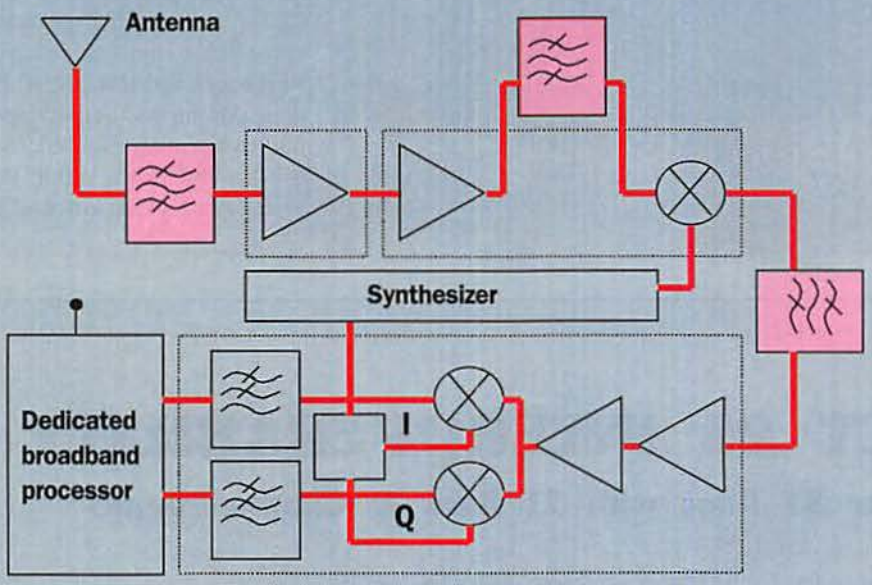
# Cognitive radios close to major advance

## Software-assisted radios are the first step toward true software radios

Cognitive radio systems in general, and true software radio (TSR) products in particular, are on the verge of revolutionizing the communications industry. TSR systems, by providing all signal processing in the software, are approaching the ultimate software-defined radio (SDR) systems goal of seamless operation in highly fragmented, multi-terminal/multi-frequency communication environments.

Such advancements are achieved by converting the signal into digital form immediately after receipt by an antenna and by dynamically downloading software corresponding to the specifics of the received signal. The progress toward SDR's ultimate goal of seamless operation in a multi-standard environment will be driven by the rate of advancement in microelectronics, particularly the increase in microprocessor computational power and a reduction in power dissipation.

Fig. 1

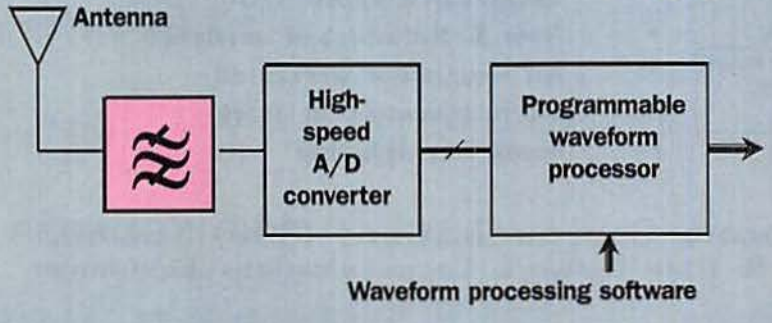



Conventional analog receiver that typically uses a double-conversion design. The architecture requires multiple external analog components (shown as pink boxes), contains many analog interfaces (shown as red lines) and can only decode one type of waveform.

The Software Defined Radio Forum—an industry initiative striving to accelerate development and deployment of SDR systems—stipulates that SDR products possess two fundamental features: flexibility toward operational standards and independence from carrier frequencies. While TSR systems possess both features, software-assisted radio (SAR) systems, in which only a portion of signal processing is done in the software, lack the reconfigurability—which must include both carrier frequency and communication protocol—to ultimately provide both features. SAR systems (Figure 1) thus can be viewed only as an intermediate step on the evolutionary path toward TSR.

In a TSR, the analog-to digital converters (ADCs) are placed as close as possible to the antenna (Figure 2), which places great demands on the ADCs' performance. All subsequent signal processing of the digitized antenna output is done by fast logic circuits and fast microprocessors

Fig. 2




Generic architecture of the TSR system.

using downloadable signal-processing software selected according to a system's operational environment.

Effective quantization of the radio signal at the antenna enables fast reconfiguration of the air interface parameters of the communication terminals. The dynamic switching of frequencies and communication protocols in the user's terminals enable the remote reconfiguration of the terminal by adding or removing system software components, with the result being greater flexibility.

**Architecturally, TSR is best defined as the software implementation of the radio transceiver receiving digitized down-converted signals from an antenna.**

Thus, TSR is the only technology that currently shows promise in delivering the ultimate SDR goal of a truly "universal" radio terminal. Other approaches are vulnerable to changes in applied standards and to introduction of new functionality.

While the significant lack of sufficient processing power currently prevents SDR from yet becoming a full-scale reality in low-power applications such as handsets, the unabated doubling of processing power each 18 months (or Moore's Law) allows some assurance that SDR-based terminals and network nodes will come to life in the not-so-remote future.

For now, however, the more realistic goal (as far as handsets are concerned) centers on developing TSR systems capable of implementing a couple of protocols per unit and providing a steady supply of power sufficient to perform signal and data processing. These criteria limit the range of current possible full TSR implementations to a stationary environment such as base stations or vehicle-based systems. Next-generation TSR components will implement digital signal process-

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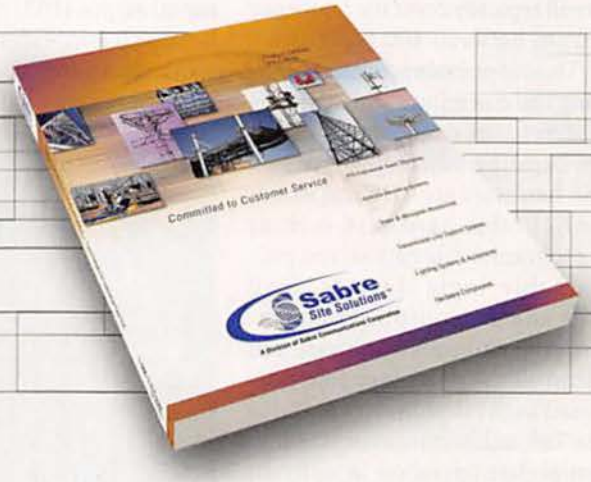


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Table 1

## Estimated performance characteristics of a delta-sigma converter

| Converter order | Second | Third |
|---|---|---|
| SNR[dB] for ΔF = 30 MHz | 55 | 80 |
| SNR[dB] for ΔF = 20 MHz | 65 | 90 |
| SNR[dB] for ΔF = 10 MHz | 75 | 100 |
| SNR[dB] for ΔF = 2 MHz | 100 | |

ing (DSP) primitives directly into the silicon, allowing for implementation in lower-power consumer devices.

An SDR suitable for commercial narrowband and broadband applications will typically cover the frequency spectrum between 400 MHz and 6 GHz. This range embraces most of the existing and emerging standards along with likely future developments.

The basic ingredients in the design of TSR hardware are ADCs, as well as reconfigurable hardware such as field programmable gate arrays, programmable logic devices, DSP boards and general-purpose computers. The embedded software can reside in all the programmable entities used in the design.

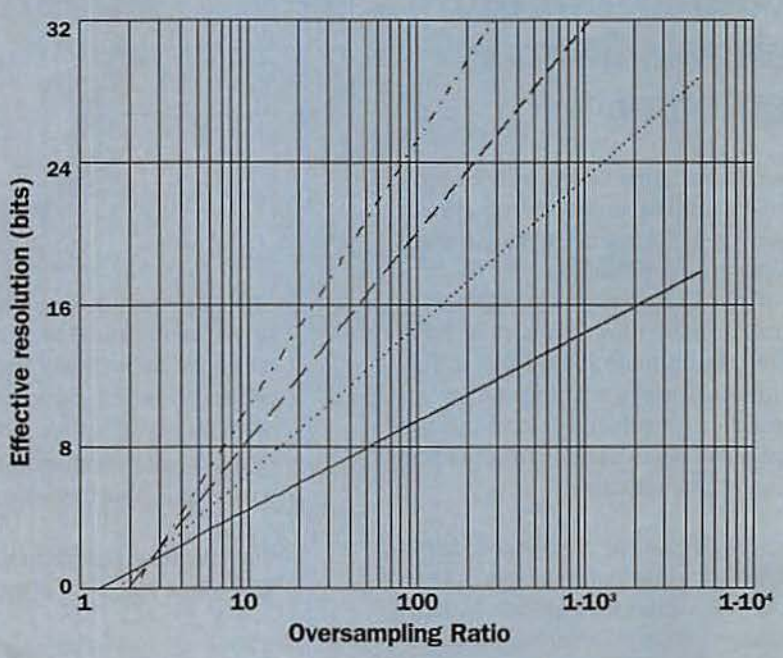
The TSR architecture must be able to accommodate operation in different environments characterized by different standards, carrier frequencies, power levels and bandwidths. Architecturally, TSR is best defined as the software implementation of the radio transceiver receiving digitized down-converted signals from an antenna. Digitization of the wireless signals' function at the antenna dramatically simplifies the implementation of transmitters and receivers. In addition to using direct down-conversion receivers versus traditional superheterodyne receivers, the architecture requires few external analog components and can be programmed to process any type of signal or multiple types of signals.

TechnoConcepts chose the Linux operating system for its TSR implementation because Linux guarantees maximum accessibility to all computer resources—such as device drivers for input/output (I/O) operations—and because it is in widespread use. Delta-sigma data conversion circuits capable of operating at clock rates in excess of 5 GHz power the transceiver.

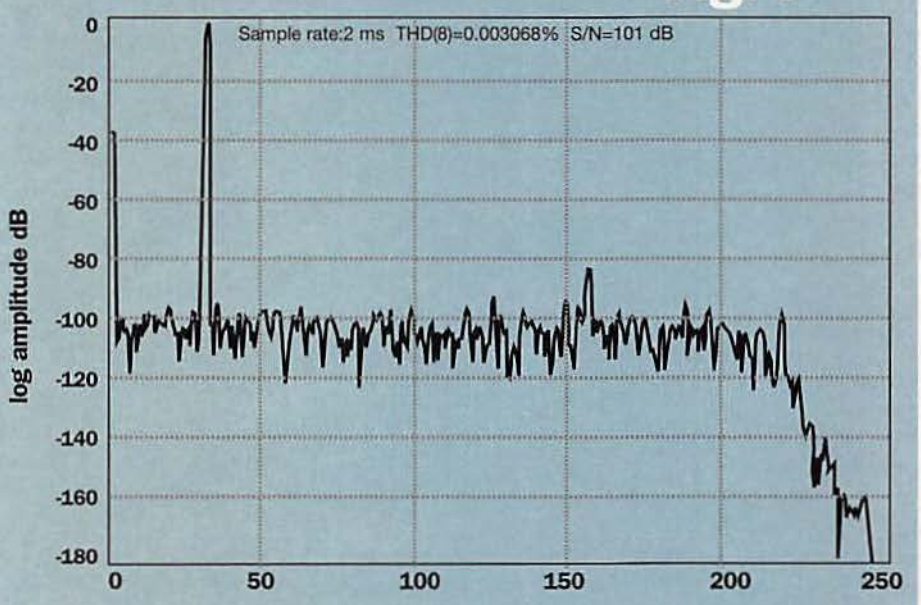
Delta-sigma converters digitize signals by modulating the analog input into a high-speed one-bit digital data stream that is subsequently processed digitally to produce a high-resolution word stream at a slower data rate. The converter is a closed-loop system in which the order of the loop and the input bandwidth may be traded for resolution. A plot of the ideal resolution for a given relative bandwidth and loop order is shown in Figure 3.

One way to improve upon the delta-sigma data converter technology is to create an architecture that simultaneously extracts the modulation from an incoming wireless signal and digitizes it with extremely high resolution. A dynamic range of 55 db to 100 dB (depending on bandwidth) is achievable using this architecture. The performance analysis of high-order delta-sigma ADC converters operating at 5 GHz shows that ex-

Fig. 3




A plot of the effective resolution of a delta-sigma converter for the first, second, third and fourth order modulators using one-bit quantization. The x-axis represents the ratio of clock rate to maximum input bandwidth (oversampling ratio). The y-axis represents resolution in bits.




Performance of CMOS technology converter at a clock rate of 10 MHz.

pected signal-to-noise (SNR) ratio depends on the operational spectrum width ΔF and the order of delta converters. The estimated SNR values in decibels for different converter orders as well as operational bandwidths, measured in MHz, are shown in Table 1 on page 26.

TechnoConcepts already has demonstrated 100 dB dynamic range using CMOS (complimentary metal oxide semiconductor) technology at a clock rate of 10 MHz, and recently demonstrated roughly a 50 dB dynamic range in its preliminary demonstration system using GaAs (gallium-arsenide) technology at a clock rate of 1.8 GHz. These results are shown in Figures 4 and 5.

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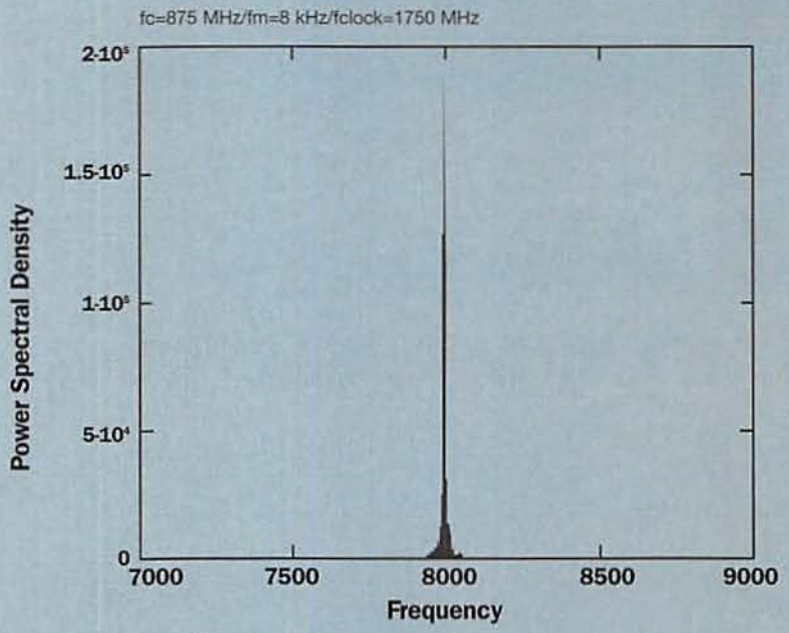
As TSR products with more powerful processing capabilities evolve, a wider range of applications will emerge. For example, a single protocol cellular phone being connected to a variety of networks through a software radio base station that serves both as a repeater and (when necessary) as a protocol translator. In this particular application, software radio handsets are not required to achieve universal access, at least in the nationwide context.

A similar concept for automobiles can be illustrated. In this case, the car has a dual mode transceiver capable of transmission and reception using a proprietary protocol and also is capable of receiving navigation signals from the Global Positioning System. This capability permits the car to transmit position information to the base station

Fig. 5




Performance of GaAs MESFET A/D converters at a clock rate of 1.75 GHz with 50 dB dynamic range.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and further allows it the universal access that is enjoyed by the handset.

The use of software radio technology would enable the car to access any cellular service and potentially be able to roam internationally. Furthermore, specialized services and capabilities (such as automobiles serving as repeaters for other automobiles and/or handsets) can be implemented without disrupting the vehicle's access to standard services. In this configuration (where both the base station networks and the access device utilize software radio technology), any wireless access device can communicate with any other wireless access device with multiple choices as to network services.

**In bandwidth-intensive broadband applications software radio technology allows service providers to dynamically use unlicensed frequency domains.**

In such an environment, the user can select the service best able to meet his needs, based on bandwidth, cost or latency. This will create a competitive cognitive radio environment where limited bandwidth use can be efficiently allocated so that the user pays only for the bandwidth he needs and no usable bandwidth remains idle.

In broadband applications, that are bandwidth intensive, software radio technology allows service providers to dynamically utilize unlicensed frequency domains to meet additional client needs when saturation has been realized on a certain frequency domain. Residential customers could be receiving video feeds on unlicensed frequency domains while business customers concurrently receive video feeds on licensed frequency domains.

The ideal SDR products must possess two fundamental features—flexibility toward operational standards and independence from carrier frequencies of received signals. Two very different types of SDR products are emerging.

The first one—SAR—is a hybrid, where a portion of signal processing (usually at high or intermediate frequencies) is done in hardware and the rest in software. Such systems achieve partial independence from carrier frequencies, but are still dependent on analog components for filtering and other signal processing operations, making them reconfigurable but not frequency agile.

The second type—TSR—uses direct down-conversion from RF to baseband immediately after receipt by an antenna. As a result, they satisfy both above-mentioned criteria. Such systems correspond to the spirit and expectations put on SDR.

Like any ultimate goal, it can be approached in an evolutionary manner, with each microelectronics advance bringing us toward multi-terminal/multi-frequency operation. ■

*Ronald M. Hickling is TechnoConcepts' co-founder and chief technology officer. He holds a masters degree in electrical engineering from UCLA and has more than 20 years experience in developing communications systems for defense and commercial contractors, beginning his career with Hughes Space and Communications in 1980. Hickling founded TechnoConcepts in 1991 and has been awarded three patents and currently has two patents pending.*

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